On the use of dual frequency nematic material for adaptive optics systems: first results of a closed –loop experiment.

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Abstract: The use of liquid crystal devices for wavefront control has been suggested and implemented by several authors. In this paper we report some preliminary results on the use of Nematic based liquid crystal devices. Several experimental efforts have been carried out in the past few months. One of the main aims was to characterize a new device that uses dual frequency nematic material in a closed loop arrangement.

OCIS codes: (010.1080) Adaptive Optics; (230.3720) Liquid Crystals

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1. Introduction

In the past few years several groups have been actively engaged in demonstrating the use of liquid crystal (LC) devices for wavefront shaping and control. The focal points of these groups are in USA [1-7], Europe [8-12], and Japan [13]. The reasons behind the use of LC for wavefront control are several. First of all is cost: the main technological push is based on the display industry, which has invested a large amount of money in developing materials, techniques and hardware that can be modified and adapted to be used for wavefront control applications. Other reasons include the low power consumption, low weight, compactness of the devices, and the fact that these are non mechanical devices with very high lifetime.

However, there are also some drawbacks. In using *nematic* materials the main problems are: polarization dependence and low temporal bandwidth. The first problem was solved by our group through the Small Business Innovative Research (SBIR) program in conjunction with Meadowlark Optics [14]. The second problem is now well under way of solution by using dual frequency material. This solution is, once again, based on an SBIR with Meadowlark Optics.

In an adaptive optics system one is adjusting the optical path (OP) of the incoming wavefront. Such adjustment can be done in two ways, if using a deformable mirror or liquid crystal device, since the OP is the product of two quantities

$$OP = \Delta z \cdot n \quad . \qquad [1]$$

Where Δz is the geometrical path and n is the refractive index of the medium. A conventional deformable mirror (DM) will modulate Δz, while a liquid crystal device will modulate n. Since nematic materials are birefringent the modulation of the refractive index happens only for one of the polarization states. One way to obviate this problem is to manufacture a device with two orthogonal layers of the the same LC material[3].

The phase modulation that can be induced by an LC cell is given by

$$\Delta\phi = \frac{2\pi}{\lambda}\int_{-d/2}^{d/2}[n(z) - n_{\perp}]dz + \Delta\Phi \quad . \qquad [2]$$

Here $n_{\perp}$ is the extraordinary component of the refractive index, d is the thickness of the cell and $<\Delta\Phi>$ is the phase component due to thermal fluctuations etc... This last term is usually negligible, for room temperature and standard thickness, for the material used in this experiment, this term is usually of the order of 10^{-7} radians. Detailed derivation of the expression for $<\Delta\Phi>$ can be found in Ref. [15]. From eq. 2 it is possible to see that the amount of phase modulation depends on the thickness of the cell. However, the thicker a cell is the slower will be its response time. A trade-off between these two parameters has to be found. Another way around the limitation of the bandwidth is to use different type of LC materials. In this paper we describe the use of the so-called dual frequency nematic material and the results of a closed loop experiment involving a device filled with such material.

2. The dual frequency LC material.

The dielectric permittivities of all liquid crystals vary with the frequency, ν, of the applied field when $\nu > 10^8$ Hz. In the low frequency range, hundreds of Hz to tens of kHz, the two components of the dielectric constant, $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are usually constant. However, for certain materials, at low frequencies, $\varepsilon_{\parallel}$ changes which leads to a change in sign of the dielectric anisotropy, $\Delta\varepsilon$. For most nematic materials $\Delta\varepsilon$ is positive at the low end of frequency range of the applied voltage, and negative at the high end. The frequency at which $\Delta\varepsilon$ reverses sign is called the *crossover frequency* ν_c. The sign reversal of $\Delta\varepsilon$ can be used to orient the liquid crystal either with the optical axis parallel ($\Delta\varepsilon > 0$) or normal ($\Delta\varepsilon < 0$) to the direction of the electric field by selecting the frequency of the applied voltage. This phenomenon is usually much faster than in the conventional nematic material, where the re-orientation is based on

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next-neighbor recall forces. Figure 1 shows the result of a test conducted on a dual frequency material modulating one wave of retardance using 38kHz and 100 Hz, respectively, as the high and low drive frequencies, with respect to the cross-over frequency of the material.

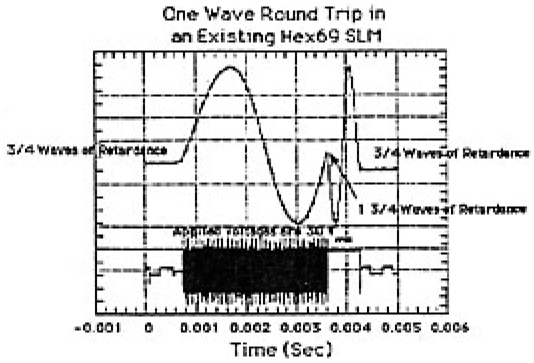

Figure 1: Measured performances of dual frequency material vs. frequency

While the use of dual frequency material has been proposed in the past, a real functioning device with independently controllable pixels has been fabricated by Meadowlark Optics only in the past year under an SBIR program with the USAF Research Laboratory. This device has 127 individually controllable elements. The overall optical quality of the device gives a residual rms wavefront error of ~$\lambda/4$, at HeNe wavelength. The device is similar to the one with 127 polarization preserving elements, described in Restaino et al. [14]. However, few meaningful differences have to be pointed out. First of all in order to work with unpolarized light, this device was built using a quarter-wave plate with a thin reflective layer deposited after the plate, following the suggestion made by Love [16]. This procedure allows a simpler control scheme, only 127 channels; however, the optical quality is lower due to intrinsic fabrication difficulties. Furthermore a small parallax error, due to the reflective nature of the device, reduces the overall 'fill factor' by a small amount, depending on the incident angle of the light.

3. Experimental Set-up and results

The set-up for the test of the closed loop performances of this device is illustrated in Fig.2. The main components of the set-up are: a Zygo interferometer, used as source of unaberrated wavefront, a Shack-Hartmann lenslet array matched to a CCD camera, DALSA 128X128, with a fast read-out frame rate. The exposure time of the CCD camera was of 10 milli-seconds. The disturbance source that generated degraded wavefronts consisted of a heat-source with a fan. In this way a dynamically changing degradation was obtained.

The results from this closed loop experiment are shown in the following video. In Fig. 3 are shown the average uncorrected and corrected images, respectively. The Strehl ratio of the average uncorrected image was 8% and the corrected image had a Strehl of 34%.

The video shows the dynamical behavior of the correction of the LC device and its capabilities to operate as an adaptive optics component. The main constraint for the closed loop bandwidth is related to the wavefront sensor software and not to the LC device itself. The 3dB rejection bandwidth of this experiment was about 20Hz. Higher bandwidth can be achieved by improving the software for the wavefront sensor reconstructor. Most of this work is under way and will give rise to a newer system with much improved capabilities.

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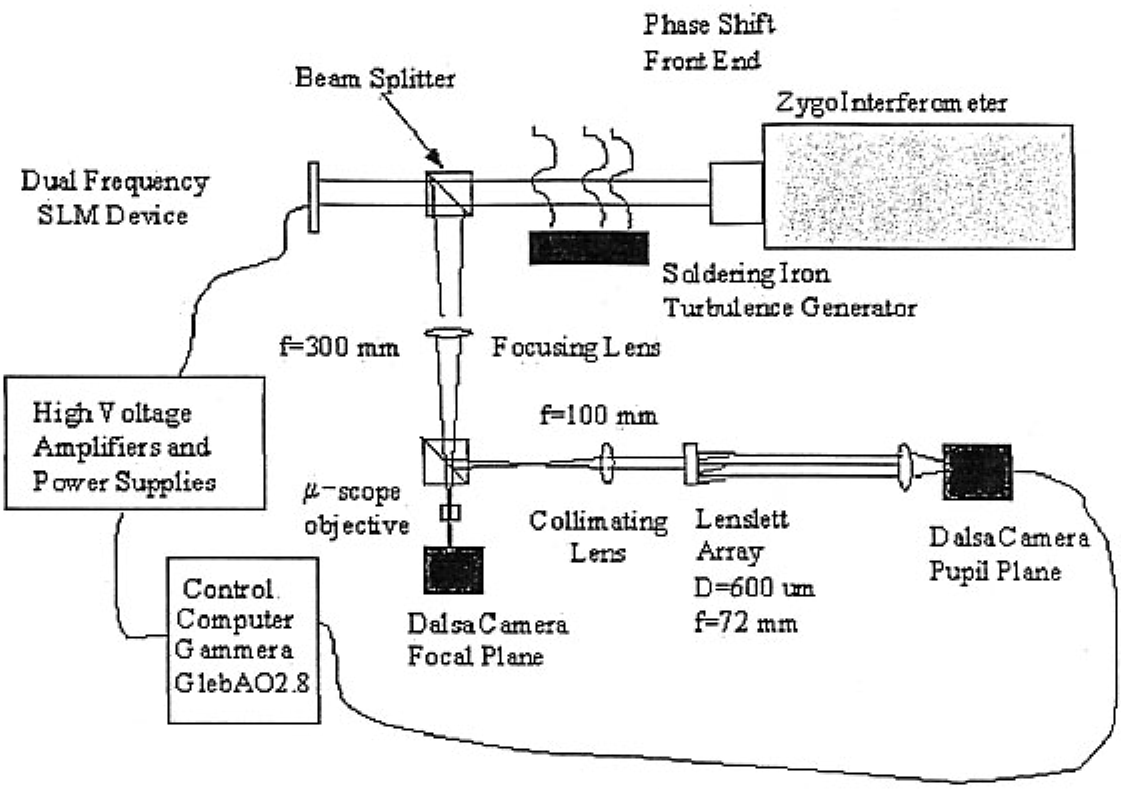

Figure 2: Schematic lay-out of the experiment

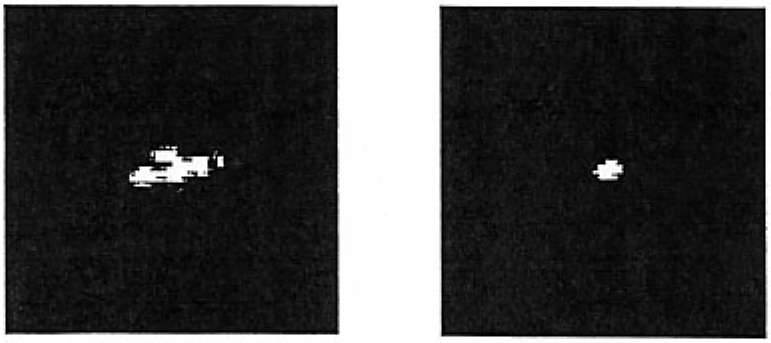

Figure 3: Average uncompensated and compensated images.

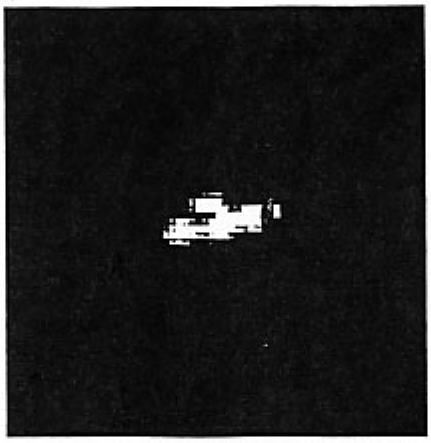

Figure 4: Video of the closed-loop experiment.(942 KB movie size)

4. Conclusions

As far as the authors are aware this is the first closed loop demonstration of a dual frequency nematic device with individually controlled pixels, used as an adaptive optics component. The device is very promising as an adaptive optics component and offers many potential advantages when compared to traditional deformable mirror technology. However, more research and testing need to be carried out in order to fully assess the capabilities of this technology.

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